MgO, dolomite, or MagAmp. Presumably, Mg release would be significantly more rapid for these materials under acidic media conditions. The sand used in these columns had an initial pH of 5.9 and little buffering capacity. Sand in columns containing MgO, MgO·MgSO₄, and dolomite had final pH values of 8.6, 8.1, and 8.1, respectively, which undoubtedly affected the solubilization of Mg from these products.

The two Florikan products were the only materials tested that exhibited typical controlled-release characteristics. The 100- and 180-d formulations released Mg at similar rates, however (Fig. 1D). These products appeared to have significant Mg release for ≈12 to 14 weeks, or about twice as long as MgO·MgSO₄. Unfortunately, these Florikan products contain only 4% Mg (Table 1) and are intended primarily for correction of K deficiency without upsetting the K : Mg balance.

The percentage of applied Mg released over 2 years varied widely among products. MgSO₄·H₂O released ≈60% of its Mg, and MgSO₄·7H₂O released ≈80% of its Mg within 4 to 5 weeks (Fig. 1A). K₂SO₄·2MgSO₄, Lutz Mg spikes, and the two Florikan products released between 60% and 80% of their Mg within 16 weeks (Fig. 1A and D). The two MgO·MgSO₄ products ultimately released ≤10% of their Mg over 40 weeks (Fig. 1B), whereas the MgO products and dolomite released <5% of their Mg over 2 years (Fig. 1B and C). MagAmp released ≈20% of its Mg over 2 years (Fig. 1C).

Although plant response to Mg fertilizers is beyond the scope of this study, it is reasonable to assume that the soluble MgSO₄-containing products release much more Mg during the first 2 weeks than plants are likely to use. In soils with high cation exchange capacities, such soluble fertilizers may provide adequate Mg over long periods of time, but in highly leached

sandy soils with poor nutrient retention, soil Mg levels will quickly drop back to inadequate levels. The insoluble Mg fertilizers such as MgO, dolomite, and MagAmp probably would never provide adequate Mg for plant growth in a neutral to alkaline Mg-deficient soil, but they may be suitable under acidic soil conditions.

In conclusion, no good, high Mg analysis, controlled-release fertilizer exists at this time, and frequently applying MgSO₄·H₂O or MgO·MgSO₄ remains the best solution for treating or preventing Mg deficiencies. The two Florikan 1N-0P-26K-4Mg products have excellent Mg and K (data not shown) release characteristics, but the Mg analysis of these products may be too low to correct Mg deficiencies.

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Preliminary Evaluation of the Effects of Fluridone in Irrigation Water on Container-grown Azaleas

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SUMMARY. In 1992, we initiated a study to determine the effects of fluridone in irrigation water applied to container-grown azaleas. Azaleas (*Rhododendron indicum* L. 'George Tabor') were grown in containers with a 3 pine bark : 1 sand mixture and were irrigated daily for 5 weeks (except weekends) with solutions containing fluridone concentrations ≤2000 g·L⁻¹. The threshold for appearance of visible injury symptoms (bleaching of new growth) was 250 g·L⁻¹ at 5 and 12 weeks after treatment initiation. Visible symptoms did not appear until at least 35 days after treatments began. No statistically significant injury occurred to azaleas treated with solutions containing fluridone concentrations <250 g·L⁻¹. This treatment rate was

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well above the maximum fluridone concentration ($<90 \text{ g}\cdot\text{L}^{-1}$) normally occurring in ponds immediately following fluridone application. It appears unlikely that even long-term irrigation of 'George Tabor' azaleas from fluridone-treated ponds would cause any significant injury.

High-quality irrigation water is critical to producing nursery container crops throughout the United States. Nursery container crops depend totally on daily irrigation. The major sources of irrigation water in many nurseries are small ponds, which often contain dense growths of aquatic weeds. The duckweed group (including the duckweeds *Spirodela* sp. and *Lemna* sp. and watermeal, *Wolffia* sp.) is second only to filamentous algae in frequency of occurrence and is among the most troublesome weeds to control in irrigation ponds. These weeds may overrun a pond totally early in the growing season and cause disruption of irrigation by clogging intakes and distribution systems. Biological control and mechanical control of these weeds are ineffective. Only one currently registered aquatic herbicide, fluridone, is effective for controlling these weeds. Fluridone may persist in pond water for ≥ 60 d (Langeland and Warner, 1986; Muir et al., 1980; Rivera et al., 1979; West and Turner, 1988; West et al., 1979). Grant et al. (1979) re-

ported that fluridone concentrations of $15 \text{ g}\cdot\text{L}^{-1}$ could be detected 120 d after a pond treatment. Plant damage, manifested as bleaching of new growth followed by necrosis and ultimately plant death may not appear until several weeks after the initial exposure. This raises concerns about the potential for nursery plant damage following fluridone application to an irrigation pond.

Current recommendations include a 30-d waiting period before treated water is used to irrigate crops (SePRO, 1994); however, this might not be sufficient for sensitive crops. Sweet corn (*Zea mays* L.) was injured when irrigation occurred 3 months after a pond treatment for watermeal control (Kay, 1991). In other tests, growth suppression in tobacco (*Nicotiana tabacum* L.) occurred when the crop was exposed to fluridone concentrations as low as $10 \text{ g}\cdot\text{L}^{-1}$, and bell peppers were damaged severely when fluridone-treated pond water was applied 8 weeks after a pond treatment (S.H.K., unpublished data).

Nursery container crops such as azaleas may receive >1 inch of irrigation per day during hot, dry periods. Dependence of these and other horticultural container crops on irrigation is increasing rapidly with advances in technology and cultural methods. The presence of phytotoxic concentrations of aquatic herbicides are unacceptable in irrigation water. Because of the high value of azaleas and other container

crops and lack of crop-specific recommendations for safe waiting periods, most nurseries are unwilling to risk fluridone treatments in irrigation ponds. Our literature search yielded no information on the sensitivity of azaleas or other container crops to fluridone.

Our objective was to determine the sensitivity of container-grown azaleas to fluridone in irrigation water.

Materials and methods

Azalea plants were obtained in mid-October from a commercial nursery (from cuttings started in August) and were transplanted into a 3 pine bark : 1 sand (v/v) substrate in 3.8-L plastic pots (15 cm in diameter). There were two plants per container with two main sprouts on each. The pine bark-sand substrate was amended with 5.0 kg Prostart (Parker Fertilizer Co., Sylacaugh, Ala.) $13\text{N}-6\text{P}_2\text{O}_5-6\text{K}_2\text{O}$ + micronutrients, 3.5 kg ground dolomitic limestone, and 1.2 kg $0\text{N}-46\text{P}_2\text{O}_5-0\text{K}_2\text{O}$ triple superphosphate per cubic meter. The transplants were placed into a greenhouse at $25 \pm 3^\circ\text{C}$ and a 12-h photoperiod, allowed a 6-week establishment period, and then placed into a completely randomized design. On the date of test initiation, plants were ≈ 10 weeks old and 20 cm tall. Fluridone solutions (0, 5, 10, 25, 50, 100, 250, 500, 1000, and 2000 $\text{g}\cdot\text{L}^{-1}$) were prepared in tap water, and 1.9 cm of irrigation was applied daily by pouring directly onto the substrate (i.e., treatments did not contact the foliage directly) over 5 weeks, except that nontreated tap water was used on the weekends to simulate occasional occurrence of rainfall. The pots were allowed to drain excess water following each irrigation to simulate natural drainage of excess water that would occur following irrigation. Each treatment was replicated five times, with one pot (containing two transplanted cuttings) per replicate. New growth was observed weekly for the appearance of fluridone injury symptoms, including bleaching and leaf necrosis. After terminating irrigation with fluridone solutions, the containers were irrigated as needed with tap water and observed for an additional 7 weeks. All testing and the subsequent 7-week observation period (after treatments were discontinued) were conducted in the greenhouse under the conditions previously indicated. The experiment

Table 1. Injury to 3.8-L-container-grown azaleas caused by fluridone in irrigation water.^z

Fluridone rate $\mu\text{g}\cdot\text{L}^{-1}$	Visual injury (%)		Time to appearance of symptoms ^y (d)	Necrotic leaves (no.)	Time to appearance of necrosis (d)	Total length of new shoots (cm)
	5 weeks	12 weeks				
0	0	0	---	0	---	943
5	0	0	---	0	---	819
10	0	0	---	0	---	680
25	0	0	---	0	---	596
50	3	2	35	<1	63	1066
100	0	5	58	0	---	874
250	10*	23*	37	4	56	925
500	20	53	35	37*	40	911
1000	57	87	35	91	35	795
2000	73	90	35	119	35	864
$\pm\text{SE}^x$	6	6	---	14	---	151

^zAn asterisk (*) indicates the threshold response to fluridone as determined by the analysis of variance and Helmert contrasts procedure ($\alpha = 0.05$). Data are the means of five replicates.

^ySymptoms were bleaching of new leaves.

^xStandard error for the overall contrasts procedure for that particular variable.

was terminated 12 weeks after the initiating fluridone treatments. At this time, the total lengths of new shoots in each container were measured, and the number of necrotic leaves on the new shoots were counted. Percent injury on new growth was estimated visually at 5 and 12 weeks. Data were subjected to an analysis of variance, and threshold toxicities were determined using a Helmert contrasts procedure (Rowell and Walters, 1976). A no-observed-effects level (NOEL) was estimated as that fluridone concentration that elicited no statistically significant damage over all variables examined (i.e., the concentration tested that was less than the lowest concentration at which any statistically significant response occurred, inclusive of all variables examined).

Results and discussion

Azalea grown in a pine bark-sand substrate and irrigated daily with 1.9 cm of fluridone-treated tap water responded slowly to the fluridone treatments. Distinct herbicide symptoms (bleaching) did not appear on new growth until ≈ 4 weeks after beginning treatments. This slow response was expected, as herbicide symptoms on azalea (W.A. Skroch, personal com-

munication) and other woody ornamentals (Smith, 1993) often do not appear until several weeks or months after exposure. No herbicide damage was visible at any fluridone treatment $< 50 \text{ g}\cdot\text{L}^{-1}$ (Table 1). Statistically significant injury occurred to all plants exposed to fluridone concentrations of $\geq 250 \text{ g}\cdot\text{L}^{-1}$, and injury continued to increase throughout the 7-week recovery period after irrigation with treated water had ceased. Threshold toxicity for percent injury and number of necrotic leaves were 250 and 500 $\text{g}\cdot\text{L}^{-1}$, respectively (Table 1). There were no significant differences in the total lengths of new shoots produced at any exposure concentration. These results suggest that azalea may be quite tolerant of fluridone in irrigation water, particularly since no significant damage occurred except at treatment rates well above the concentrations normally found in treated pond water [the maximum labeled rate is only 90 $\text{g}\cdot\text{L}^{-1}$ for ponds (SePRO, 1994)]. However, a substantial proportion of the fluridone (not measured) may have been bound in the potting mixture, since it binds readily to organic matter (Shea and Weber, 1980, 1983; Weber, 1980). We also expected some loss (not measured) from leaching from the substrate after each application of irrigation water.

The NOEL estimated from these data was $100 \text{ g}\cdot\text{L}^{-1}$. Fluridone concentrations as high as $100 \text{ g}\cdot\text{L}^{-1}$ would be rare in a treated pond and would occur only during the first day or two immediately following treatment. Mixing and photolytic decomposition (Saunders and Mosier, 1983) rapidly would reduce the fluridone in the water below this concentration. Therefore, it is unlikely that container-grown azaleas would be injured by fluridone-treated irrigation water since fluridone concentrations causing injury were well above those that would occur in a pond, even immediately following treatment.

Further research is needed to determine whether other azalea varieties are as tolerant to fluridone as 'George Tabor' and to determine the sensitivity of new transplants. Also, examination of azalea injury over a longer posttreatment period is needed to determine whether long-term effects might appear several months to 1 year after cessation of exposure to fluridone-treated irrigation water. Examination

of the sensitivity of other woody ornamental container crops to fluridone also is warranted.

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